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Reasoning of Young Adults and Introductory Physics: What's the Connection?

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Vicki Plano Clark's essay
on
Reasoning of Young Adults and Introductory Physics: What's the Connection?
University of Nebraska Lincoln
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Dr. V. Plano Clark, as a part of her PhD program, wrote a number of essays for her graduate course in educational psychology, Cognitive Development, #961, taught by Professor David Moshman. Her primary reference for this essay is a chapter by Professor Moshman in the Handbook of Child Psychology, the exact citation is given below:

David Moshman. (1998). Cognitive development beyond childhood. In W. Damon (Series Ed.) & D. Kuhn & R. Siegler (Vol. Eds.), *Handbook of child psychology: Vol. 2. Cognition, perception and language* (5th ed., pp. 947-978). New York: Wiley.

In addition, Dr. Plano Clark made extensive use of the work of Robert Karplus in studying reasoning beyond elementary school.

Reasoning of Young Adults and Introductory Physics: What's the Connection?

Moshman's discussion in his chapter from the Handbook of Child Psychology (1998) is very relevant to my work with young adults at UNL and to my interests in physics education. While there are many possible topics upon which I could write in this essay, one statement from this chapter in particular resonated with me and will serve as the starting point of my essay. This statement was as follows (emphasis added):

"Legal thinking may be defined as thinking aimed at determining what the law requires or forbids. *It is often argued that legal education should be aimed at teaching a student how to "think like a lawyer," that is, to engage in legal reasoning.*" (p. 955)

This statement stood out to me because this is exactly what has been frequently stated as the reason that many students (particularly those pursuing careers in the biosciences and health sciences) are required to take introductory physics. In fact, I believe many bioscience faculty, advisors, and professional school staff, who are unfamiliar with cognitive development, would be entirely comfortable with the following analogous statement.

"Physics thinking may be defined as thinking aimed at solving scientific problems. *It is often argued that physics education should be aimed at teaching a student how to "think like a physicist," that is, to engage in scientific reasoning.*" (p. 955)

If you are willing to accept that this is a fair statement about the beliefs commonly held about the introductory physics course, then I think that a number of related questions and issues immediately come to mind and call for further discussion. Three of these questions are discussed below.

(1) What kinds of reasoning are utilized in introductory physics?

Moshman defined general reasoning as "the deliberate application of epistemic constraints to one's own thinking" (p. 947) and argued that it represents a more advanced form of cognition than inference or thinking (pp. 952-3). He identified three broad categories of reasoning with corresponding sub categories. Here is a brief description of a selected subset of three kinds of reasoning that seem particularly relevant to introductory physics. In addition, I include my ideas of how a student studying introductory physics may be called upon to use them.

- **Analogical reasoning** (p. 954) - Reasoning requiring explicit recognition of a second-order relation of equality between two first-order relations, of the general form a is to b as c is to d . Also known as proportional reasoning when describing mathematical analogies.

Students studying introductory physics are constantly asked to use proportional reasoning in investigating physics phenomena and working typical textbook problems. This is true from the first class when students are expected to be able to make unit conversions and continues in more sophisticated forms throughout the semester. A typical problem would ask students to compare the force on a charged particle if the distance was increased by a factor of 3, knowing that the force obeys the form $F = -\frac{kq_1q_2}{d^2}$. The ability to use proportional reasoning is definitely assumed by most physics instructors and physics textbooks.

- **Combinatorial reasoning** (p. 958) - A kind of probabilistic reasoning requiring explicit recognition of systems for generating all possible permutations, combinations, or other arrangements of a set of elements.

Essentially all concepts of introductory physics are demonstrated and defined based on experimental evidence presented to or experienced by students. In order for these experiments to be meaningful to students and challenge their physical conceptions, they must interpret the results using statistical and probabilistic reasoning. In addition, when designing and understanding experiments, they need to be able to control variables and consider all possible combinations of the variables relevant to the physical system under investigation.

- **Correlational reasoning** (p. 958) - Reasoning requiring appropriate coordination of frequencies with respect of each of all possible combinations.

In an introductory physics lab, students may be directed or asked to collect all sorts of data. However, in order to make sense of this data and to be able to reason through to meaningful conclusions, the students need to be able to systematically apply sophisticated rules for assessing covariation in data. This reasoning ability becomes more important as students are asked to create general models from empirical data.

(2) What levels of reasoning capabilities do introductory physics students possess?

Many cognitive psychologists and physicists have recognized that educators' implicit expectations about students' advanced reasoning capabilities are a part of much of our educational environment, including but not limited to the teaching of introductory physics. Some of these scientists subsequently devised means to measure and assess the reasoning levels of students. Often these measures resulted in the creation of paper and pencil activities known as "reasoning puzzles" (e.g., The Piaget Workshop, 1975). I have attached an example set of reasoning puzzles that address the three forms of advanced reasoning described above (proportional, combinatorial, and correlational). In addition, I am including a puzzle that addresses conditional reasoning similar to that of the Four-Card Task.

These reasoning puzzles (and others like them) have been used in a number of research studies (see sample references). In addition, they have also been given to students enrolled in introductory physics courses. Here is a brief example of the results that were obtained at UNL in an introductory physics course for freshman pursuing non-science majors (M. Plano Clark, 1994).

Kind of Reasoning	Percent of students who did not demonstrate advanced reasoning	Percent of students who demonstrated transitional advanced reasoning	Percent of students who demonstrated advanced reasoning
Proportional	55	5	45
Combinatorial	60	15	25
Correlational	15	35	50
Conditional	25	65	10

Although the details of these results are not presented here, I hope it is apparent that a large number of UNL undergraduates have not mastered advanced reasoning abilities.

(3) What's the connection between students advanced reasoning and the introductory physics course?

In this discussion, I have tried to briefly present three major points: (1) many students are asked to take physics to develop their reasoning skills, (2) physics courses, even at the introductory level, make extensive use of advanced student reasoning, and (3) many of the students who take introductory physics do not demonstrate advanced reasoning capabilities.

Putting these three points together leads me to propose many more questions, most of which do not have easy answers. Some questions relate to the mechanics of teaching introductory physics. For example, can students succeed in a traditional, lecture-based physics course if they are not already able to demonstrate advanced reasoning? How should assessments be designed if an instructor knows his/her students possess varying levels of advanced cognition? Why don't more instructors use active engagement curricula that facilitate active reflection, coordination, and peer interaction for the enrolled students?

Another subset of questions are more broad, such as can the physics department accept the role of trying to promote the development of advanced reasoning in college students? Even if it does, can one course make much difference? Shouldn't a major role of all courses at the university be to promote the development of advanced reasoning? What would have to change in the culture of the university to make this happen?

References in my essay:

"Using Reasoning Puzzles in an Introductory College Physics Course," M. W. Plano Clark and Robert G. Fuller, American Association of Physics Teachers Winter Meeting, Orlando, FL, January 1995; AAPT Announcer, 24 (4), 84, 1994.

Karplus, R., et. al., 1975, Workshop on Physics Teaching and the Development of Reasoning, American Association of Physics Teachers, Stony Brook, NY.

References Related to Reasoning Puzzles:

E. F. Karplus and R. Karplus, Intellectual Development Beyond Elementary School I: Deductive Logic, School Science and Mathematics, 1970, 70(5), 398-406.

R. Karplus and R. W. Peterson, Intellectual Development Beyond Elementary School II: Ratio, A Survey, School Science and Mathematics, 1970, 70(9), 813-820.

R. Karplus and E. F. Karplus, Intellectual Development Beyond Elementary School III: Ratio, A Longitudinal Study, School Science and Mathematics, 72(8), 1972, 735-742

E. F. Karplus, R. Karplus and W. Wollman, Intellectual Development Beyond Elementary School IV: Ratio, The Influence of Cognitive Style, School Science and Mathematics, 74(10), 1974, 476-482.

W. Wollman and R. Karplus, Intellectual Development Beyond Elementary School V: Using Ratio in Differing Tasks, School Science and Mathematics, 74(11), 1974, 593-613.

R. Karplus, E. F. Karplus, M. Formisano and A.-C. Paulsen, A Survey of Proportional Reasoning and Control of Variables in Seven Countries, Journal of Research in Science Teaching, 1977, 14(5), 411-417

H. Adi, R. Karplus, A. E. Lawson, and S. Pulos, Intellectual Development Beyond Elementary School VI: Correlational Reasoning, School Science and Mathematics, 1978, 78(8), 675-683.

B. Kurtz and R. Karplus, Intellectual Development beyond Elementary School VII: Teaching for Proportional Reasoning, School Science and Mathematics, 1979, 79(5), 387-398.

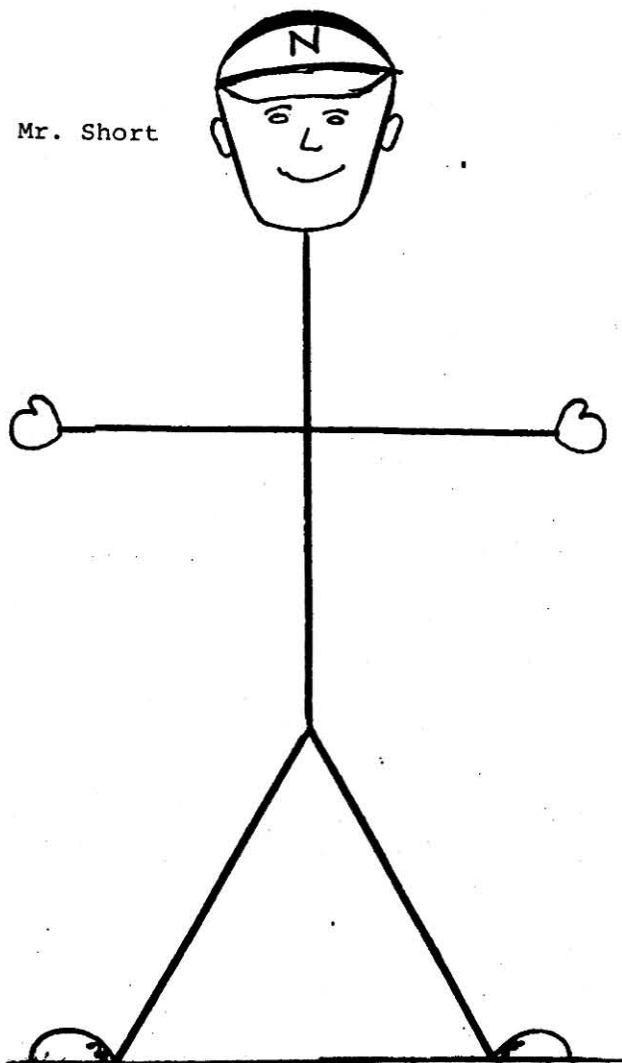
R. Karplus, H. Adi and A. E. Lawson, Intellectual Development Beyond Elementary School VIII: Proportional, Probabilistic, and Correlational Reasoning, School Science and Mathematics, 1980, 80(8), 673-678.

H. Adi, R. Karplus, and A. E. Lawson, Conditional logic abilities on the four card problem: assessment of behavioral and reasoning performances, Educational Studies in Mathematics, 1980, 11, 479-496.

The Mr. Short - Mr. Tall Puzzle [Proportional Reasoning]

The figure below is called Mr. Short. We used large round buttons laid side-by-side. To measure Mr. Short's height, starting from the floor between his feet and going to the top of his head. His height was four buttons. Then we took a similar figure called Mr. Tall, and measured it in the same way with the same buttons. Mr. Tall was six buttons high.

Mr. Short



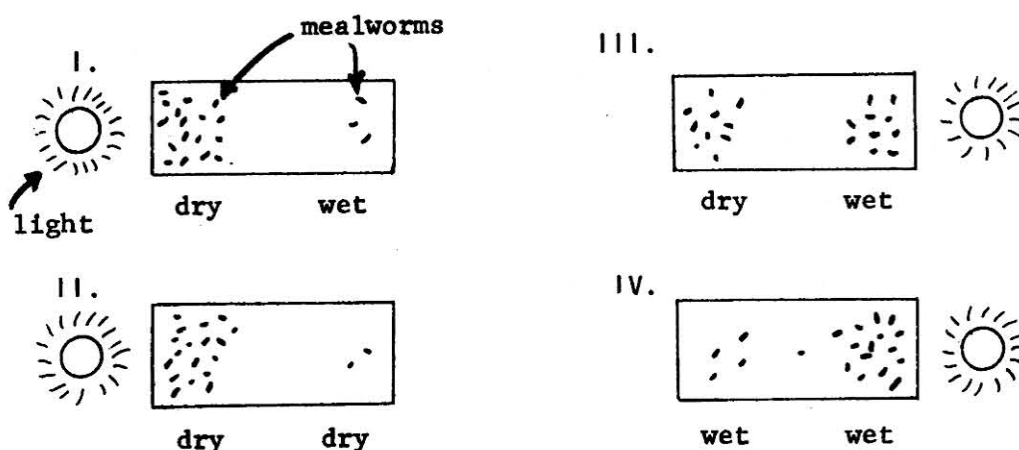
Now please do these things:

1. Measure the height of Mr. Short using paper clips in a chain provided. The height is _____.
2. Predict the height of Mr. Tall if he were measured with the same paper clips. _____.
3. Explain how you figured out your prediction. (You may use diagrams, words or calculations. Please explain your steps carefully.)

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The Mealworm Puzzle [Correlational Reasoning]

Some experimenters wanted to test the response of mealworms to light and moisture. To do this they set up four boxes as shown in the diagram below. They used lamps for light sources and constantly watered pieces of paper in the boxes for moisture. In the center of each box they placed 20 mealworms. One day later they returned to count the number of mealworms that had crawled to the different ends of the boxes.



What can you conclude from these diagrams?

The diagrams show that mealworms respond to (response means move toward or away from):

- A) light but not moisture.
- B) moisture but not light.
- C) both light and moisture.
- D) neither light nor moisture.

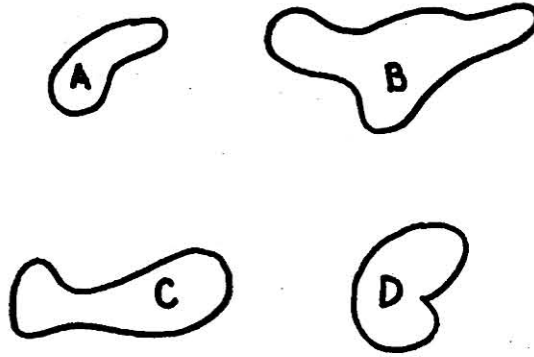
Please explain your choice. _____

How did you think your way through the problem? Did you think at once of the way to do it, or did you first think of a way that had to be modified or abandoned?

6/8

The Islands Puzzle [Conditional Reasoning]

The puzzle is about Islands A, B, C, and D in the ocean. People have been traveling among these islands by boat for many years, but recently an airline started in business. Carefully read the clues about possible plane trips at present. The trips may be direct or include stops and plane changes on an island. When a trip is possible, it can be made in either direction between the islands. You may make notes or marks on the map to help use the clues.



First Clue: People can go by plane between Islands C and D.

Second Clue: People cannot go by plane between Island A and B, even indirectly.

Use these two clues to answer Question 1. Do not read the next clue yet.

Question 1: Based only on these two clues, can people go by plane between Island B and D?

Yes _____ No _____ Can't tell from the two clues _____
Please explain your answer.

Third Clue: People can go by plane between Island B and D.
(do not change your answer to Question 1 now!)

Use all three clues to answer Question 2 and 3.

Question 2: Can people go by plane between Island B and C?

Yes _____ No _____ Can't tell from the three clues _____
Please explain your answer.

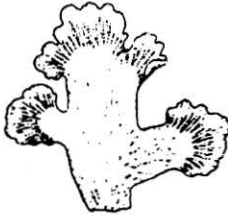
Question 3: Can people go by plane between Islands A and C?

Yes _____ No _____ Can't tell from the three clues _____
Please explain your answer.

7/8

Algae Puzzle [Combinatorial Reasoning]

A population of crabs which eats algae lives on a seashore. On the seashore there are four kinds of algae: yellow, red, brown, and green algae.



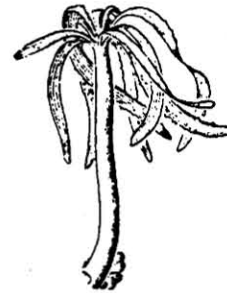
Yellow -- Y



Red -- R



Green -- G



Brown -- B

Dr. Saltspray, a biologist, is interested in determining which of the types of algae are actually eaten by the crabs. He plans to find out by examining the stomach contents of the crabs. Before he does his investigation he lists every interesting possibility he thinks he may find in the stomachs. Write down every possibility he can find. Use letters Y, R, G, and B to save space.



Looking back, how did you think you way through the problem? Did you think at once of the way to do it, or did you first think of a way that had to be modified or abandoned?
